Title:

Optical Fiber Array with Precise Fiber Positioning

BACKGROUND OF INVENTION:

The present invention relates to fiber optic arrays and more particularly to large, matrix configured arrays and the method and tools for making the same. Fiber optics has been the driving force in the communication revolution which has enabled carriers to achieve enormous data throughput. In order to realize the full potential of the technology, fiberoptics will be incorporated into every facet of the integrated electronics, which will then make it possible to fully utilize the enormous bandwidth of the optical fiber with the high speeds of the semiconductor integrated circuitry. To this end, arrays of optical fibers need to be coupled precisely and reliably to semiconductor laser and detector arrays on a chip. Already, various groups throughout the world have

demonstrated feasibility of high-speed optoelectronic VLSI switching and two dimensional fiberoptic arrays for an optical crossbar switch. In 1996, reports were published of achieving approximately + or -5 micrometer fiber positional accuracy. In June 1997, Messrs. J. Sherman et al. filed and obtained on May 25, 1999 US Patent No. 5,907,650 by Fiberguide Industries, Inc. relating to a new method and array achieving at least + or -2 micrometer fiber positional accuracy. Although these advances in the art enhance the accuracy and reliability of fiber arrays, they introduce or amplify other technical problems that must be solved to satisfy industry's need for large number, reliable, high precision, fiber matrix arrays. For example, as the demand for the number of fibers in matrix arrays increases, from 8 x 8 just a few years ago to the present more than 128 x 128, assembly problems arise because of the difficulty in handling and positioning and securing the large number of fibers in the assembly.

SUMMARY OF EXEMPLARY EMBODIMENT OF THE PRESENT INVENTION:

A primary object of the present invention is to provide new connector apparatus and methods of assembly that solve the aforementioned problems, provide an efficient and reliable manufacturing method for such large

element number arrays and produce such a fiber array connector matrix with highly accurate and reliable fiber placement that is sufficiently robust for further installation and use in the field.

Another primary object of the present invention is to provide such an optical array with enhanced precision compared to the known prior art, which can be effectively and efficiently manufactured, with lower unit costs than currently available products. This is accomplished, according to the principles of the present invention by providing a front mask with fiber seating opening side walls and means for pressing the inserted fiber outer surface against those walls for secure and precise lateral positioning. Each opening can be any suitable shape and bonding material, preferably fills the voids between the fiber and opening walls.

One exemplary embodiment according to the principles of the present invention includes a front mask wafer, a clamping wafer, and a rear wafer mounted to the front face of a suitable housing. Each wafer includes openings of suitable shape, longitudinally aligned and slightly larger than the fiber to allow easy longitudinal insertion. In one example, the openings are generally square or rectangular in shape with the corner-to-corner diameter arranged in a

predetermined direction, such as vertically. Once all desired fibers are inserted into all predetermined mask openings, the clamping wafer is moved slightly in the predetermined direction so that its opening upper walls force the respective fiber against the lower walls of the front mask and rear wafer openings. This action presses the fiber in a precise position relative to the front mask-opening array. The clamping wafer is then secured relative to the housing and bonding material is applied as desired. Grinding and polishing the bonding material, fiber tip and front mask surface completes the sub-assembly preparation. Some of the benefits of this method include easy fiber insertion without having to etch or shape the tip to a conical shape although, it does not preclude each pre-shaping. Also, the method accommodates insertion and securing ribbon fibers which are assured of being of the same length in the final assembly.

An alternate embodiment precisely secures the fibers in the array by providing a wafer with unconnected openings that have a transverse dimension slightly smaller than that of the fiber outer diameter. The wafer material defines two sides of each opening which are etched or otherwise shaped into one or two flexible independently movable arms extending away from the opening. The proximal end of each

arm is integral with the main wafer body. The arm(s) distal end(s) deflect in response to the fiber insertion causing the fiber to seat against the other two, non-movable sides of the opening. Bonding, polishing, finishing follows all fiber seating. In one embodiment, the opening is square and each of two adjacent sides comprise a flexible arm, and the arms press the fiber into engagement with the other two sides of the square opening.

Other and further objects and benefits of the present invention shall become apparent with the following detailed description of exemplary embodiments when taken in view of the appended drawings, in which:

Figure 1 is an exploded perspective view of one exemplary embodiment according to the principles of the present invention.

Figure 2 is similar to Figure **1** showing the parts assembled prior to displacement of the second wafer.

Figure 3 is a partial front view of the area around one of the front wafer openings after the second wafer is displaced.

Figure 4 is a perspective view of the first or third wafer of Figure **1**.

Figure 5 is a perspective of the second wafer of Figure **1**.

Figure 6 is a partial front view of an alignment hole area of Figure **4.**

Figure 7 is a partial front view of an alignment hole area of Figure **5.**

Figure 8 is a partial side view of the first, second, and third wafers of Figure **3.**

Figure 9 is similar to Figure 1 showing an alternate embodiment according to the principles of the present invention.

Figure 10 is a partial front view of a portion of the front wafer mask.

Figure 11 is an enlarged view of one of the elements of opening **42** in Figure **10.**

Figure 12 is a section view taken along line 12 - 12 of Figure **11.**

Figure 13 is a section view taken along line 13 - 13 of Figure **11.**

Figure 14 is a section view taken along line 14 - 14 of Figure **10.**

Figure 15 is similar to Figure **11** showing an alternate embodiment for the elements of seat **42.**

Figure 16 is a pictorial, persective, partial view of the rear face of a guide mask and front mask with fibers shown

extending rearward of yet a further alternate embodiment according to the present invention.

Figure 17 is a rear view of the front mask of Figure **16** before the fibers are installed.

Figure 18 is an enlarged partial view of the lower left corner of Figure **17.**

Figure 19 is a further enlarged partial view of one of the slot and elongated member segments of Figure **18.**

Figure 20 is similar to Figure 18 with the fibers installed.

Figure 21 is an enlarged partial view of Figure **20** showing one of the fibers seated in a front mask opening and contacting the flexible member.

Figure 22 is an exploded partial perspective view of the rear of the front mask showing the seated fibers and one of the flexible members pulled rear-ward to show the seated fiber end.

Figure 23 is a reduced view of Figure **22** also showing the rear of the guide mask or wafer **91.**

DETAILED DESCRIPTION OF EXEMPLARY EMBODIEMENTS OF INVENTION

One exemplary embodiment of an optical fiber array according to the principles of the present invention is shown in Figures **1 - 8.** Array assembly **10** includes a

suitable housing **5** to house and secure array of optical fibers **6** and first wafer **1**, a second wafer **2**, and a third wafer **3** include openings **12, 14**, and **16**, respectively, arranged in predetermined congruent patterns such as rows and columns generally as shown. As described below wafers **1, 2**, and **3** are openings **12, 14**, and **16** cooperate to initially seat and ultimately precisely secure each fiber at a precise position prior to subsequent process steps of application of epoxy, grinding, polishing and assembly of the final array apparatus. Wafers **1, 2, 3** can be made of any suitable material for the precise formation and positioning of openings. Etched silicon wafers is one example of a suitable material and hole formation technique. In this example openings **12, 14, 16** are generally square or diamond shaped with one diameter vertically oriented, however, other shapes and orientations can be used.

It is important that the opening arrays of wafers **1, 2, 3** be precisely aligned with each other and with other elements of the final array apparatus or connector. In this example wafers **1, 2, 3** include alignment holes **18, 20**, and **22** respectively to accommodate positioning pins **4**. However, holes **22** are vertically elongated to permit slight

vertical displacement of wafer **2** relative pins **4** and wafers **1, 3**.

In this example wafer support **7** serves to mount the front wafers **1, 2, 3** and includes fiber guide openings **24** to aid in fiber insertion from the rear. Support **7** and housing **5** also includes positioning holes **26** and **28**, respectively.

During assembly, the parts are assembled generally as shown in Figure **1**. The wafers **1, 2, 3** and support **7** are precisely aligned and all opening arrays aligned and parts seated and installed on housing **5**. Fibers **6** are then installed and secured by any suitable method, such as those disclosed in U.S. Patent Application SN. 09/841,686 filed April 24, 2001. Since openings **12, 14,** and **16** are larger than the fiber diameters, fibers **6** easily enter and extend through the aligned wafer openings. See Figure **2**. Once all fibers are seated with their tips extending through wafer **1** front face, wafer **2** is displaced, e.g., downward so that the sidewalls of openings **14** clamp or press respective fibers against the sidewalls of openings **12** and **16** of wafers **1** and **3**. This clamping action can be seen in Figure **3** and Figure **8** hereof. One example of achieving displacement of wafer **2** is by use of spring actuator **30** that aligns on the top of wafer **2**. Pressing on the top,

center section of spring **30** causes wafer **2** to slide downward until the total clamping forces on all fibers overcome or resist the spring pressure. The vertically elongated openings **20** in wafer **2** enable the downward displacement. Spring **30** can continue to apply clamping pressure, if desired, until epoxy or bonding material can be applied and cured or otherwise harden to hold the various elements in place. Thereafter, the front face can be ground, polished, or otherwise treated as desired. The resulting assembly includes precisely positioned array of optical fibers.

It will be understood by those of ordinary skill in this art that various fixtures and standard devices can be used to retain housing **5** and other parts during assembly including positioning and retaining spring **30** until various parts are secured by cured or bonded materials.

An alternate embodiment according to the principles of the present invention includes a front wafer mask with individual fiber seats that clamp the fiber in precise positions. One example is shown in Figures **9** - **14** wherein front mask **40** includes an array of seats **42**. In this example each seat **42** includes an opening **44** defined by stationary sidewalls **46, 48**. A pair of flexible arms **50, 52** have their proximal ends **54, 56** integral with the

stationary wafer and their distal ends **58, 60** free to move in the direction normal to the axial direction of the fiber.

Each end **58, 60** includes a surface **62, 64** that bounds opening **44**. As better seen in Figures **12, 13** distal ends **58, 60** are preferably the same thickness as the wafer **40** and at least the mid-region of arms **50, 52** are etched to a thinner dimension to provide suitable flexing and spring action for arms **50, 52**. In addition the various slots that define arms **50, 52** and distal ends **58, 60** are also precisely etched to enhance precise positioning of the seated fiber.

In operation, wafer **40** is mounted to housing **5** by pins **4** or other suitable means spacer or guide masks **7** can be used as desired. Fiber **6** can be inserted individually or one row or column at a time or in some other sequence as desired. As each fiber tip is inserted through its respective seat **42**, the fiber encounters the distal end **58, 60** sidewalls **64, 62**. The contact or frictional forces applied to ends **58, 60** as fiber **6** advances forward are sufficient to bend or flex arms **50, 52** generally within the wafer plane to enlarge opening **44** causing ends **58, 60** to apply a slight spring or clamping force on fiber **6** surface urging fiber **6** against the precisely positioned stationary

walls **46, 48** of opening **44.** Once fully seated, arms **50, 52** continue to apply suitable clamping force on fiber **6** to secure the same while other fibers are seated in wafer **40** and subsequent process steps are performed, such as application of epoxy or bonding material, grinding, polishing, etc.

An alternate configuration of elements for seats **42** is shown in Figure **15.** The shape of opening **70** is generally triangular and a single arm **50** clamps fiber **6** against stationary walls **46,** and **48** generally as shown. Fiber insertion, seating, and clamping is essentially the same as described above except only the single arm **50** and distal end **58** flex and apply clamping force on fiber **6** instead of the two flex arm arrangement of Figure **11.**

Another embodiment according to the principles of the present invention is shown in Figures **16 - 21** wherein the front mask **82** includes a series of elongated slots **84** which are etched or laser cut through the wafer. The wafer defines a number of projections or dimples **86** spaced along the length and extending into each slot. Prior to fiber insertion, an elongated flexible member **90** is positioned from the back of the front mask along and within each slot generally as shown in Figure **18** and has each end held between projections **86** and an upstanding projection **87**

between the two outer projections **86**. Member **90** can be made of polymide coated optical fiber, glass fiber, monofilament fishline or similar materials with the proper diameter or polyimide tubing, or any other suitable material. Wafer **82** also defines a series of fiber seats **88** formed through the wafer adjacent each slot bottom such that the opening in each seat **88** opens into or communicates with the slot. The cross sectional shape of seat **88** could be any suitable shape such as V-shaped or modified diamond-shaped generally as shown. Once members **90** are installed the rear wafer or guide mask **91** is positioned in contact with the rear of mask **82**.

As better seen in Figures **20, 21,** after the two masks are assembled, fibers **6** can be inserted into seat openings in any suitable manner such as by row, column, individually or any other suitable sequence. Fiber **6** tips can be conically shaped to facilitate insertion and guide mask **91** can be used as desired. As each fiber **6** enters seat **88** opening its sidewalls engage the stationary sidewalls of seat **88**. The outer (top) surface area of fiber **6** also engages the underside of member **90** and raises member **90** slightly. Projections **86** are positioned on either side of each seat **88**. The flexed portion of member **90** presses or clamps fiber **6** precisely against the bottom two walls of

seat **88** to precisely position fiber **6.** Note each fiber **6** flexes a small portion of member **90** and each fiber **6** seating contributes to the overall pressure applied by member **90** on the full set of fibers in the row. Once the row is finished the tension in the flexible member is enough to push the fibers into the bottom of the holes. The epoxy is then applied on the fibers to fill voids and cured to hold the fibers in place.

It should be understood that none of the drawings hereof are necessarily drawn to scale and dimensions are exaggerated to convey conceptual understanding. Fiber tips can be shaped to facilitate insertion through wafer holes and seats if desired. Various other improvements and modifications can be made to the exemplary embodiments disclosed herein without departing from the spirit and scope of the present invention.